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STUDY OF SCALAR TOP QUARKS AT A FUTURE e^+e^- LINEAR COLLIDER

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Abstract

The scalar top discovery potential has been studied with a full-statistics background simulation for $\sqrt{s} = 500$ GeV and $\mathcal{L} = 500$ fb^{-1}. The simulation is based on a fast and realistic simulation of a TESLA detector. The large simulated data sample allowed the application of an Iterative Discriminant Analysis (IDA) which led to a significantly higher sensitivity than in previous studies. The effects of beam polarization on signal efficiency and individual background channels are studied using separate optimization with the IDA for both polarization states. The beam polarization is very important to measure the scalar top mixing angle and to determine its mass. Simulating a 180 GeV scalar top at minimum production cross section, we obtain $\Delta m = 1$ GeV and $\Delta \cos\theta_{\tilde{t}} = 0.009$.

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1 Introduction

The study of the scalar top quarks is of particular interest, since the lighter stop mass eigenstate is likely to be the lightest scalar quark in a supersymmetric theory. The mass eigenstates are $m_{\tilde{t}_1}$ and $m_{\tilde{t}_2}$ with $m_{\tilde{t}_1} < m_{\tilde{t}_2}$, where $\tilde{t}_1 = \cos\theta_{\tilde{t}}\tilde{t}_L + \sin\theta_{\tilde{t}}\tilde{t}_R$ and $\tilde{t}_2 = -\sin\theta_{\tilde{t}}\tilde{t}_L + \cos\theta_{\tilde{t}}\tilde{t}_R$. We study the experimental possibilities to determine $m_{\tilde{t}_1}$ and $\cos\theta_{\tilde{t}}$ at a high-luminosity e^+e^- linear collider like the TESLA project [1] with the possibility of polarizing the e^- beam. The MSSM cross section was calculated with CALVIN2.0 [2].

Previously, the discovery potential for scalar top quarks was simulated for $\sqrt{s} = 500$ GeV and $\mathcal{L} = 10$ fb^{-1} where sequential cuts for the event selection were applied [3,4,5]. The possibility of beam polarization to determine mass and mixing angle was studied [6,7] and resulting estimates of the errors of the soft-breaking parameters in a supersymmetric theory were given [8]. The 10 fb^{-1} study gave 4.3% signal efficiency with 21 signal and 9 background events, which resulted in $\Delta m = 7$ GeV and $\Delta\cos\theta_{\tilde{t}} = 0.06$.

[a] speaker

2 Event Simulation

The simulated production process is $e^+e^- \rightarrow \tilde{t}_1\bar{\tilde{t}}_1$, where subsequently each scalar top decays into a c-quark and a neutralino which escapes detection. The resulting signature is two jets and large missing energy. This channel is dominant unless the decay into a chargino is kinematically allowed. The previous 10 fb^{-1} analysis gave slightly higher sensitivity in the chargino channel. The signal generator [9] includes initial state radiation and beamstrahlung. The generated events are passed through the parametric detector simulation SGV [10] tuned for a TESLA detector [1]. We simulate a 180 GeV scalar top and a 100 GeV neutralino.

3 Event Preselection

The event selection consists of several steps. First, an event preselection is applied using the hadronic character and large missing energy of the simulated signal. The same preselection as for the 10 fb^{-1} study is used and we checked that similar fractions of events in each background channel pass in this 500 fb^{-1} analysis. The following preselection cuts are applied: $25 < N_{\mathrm{cluster}} < 110$, $0.2 < E_{\mathrm{vis}}/\sqrt{s} < 0.7$, $E_{\parallel}^{\mathrm{imbalance}}/E_{\mathrm{vis}} < 0.5$, thrust < 0.95, $|\cos\theta_{\mathrm{thrust}}| < 0.7$. The number of simulated events for the signal and for each background channel, as well as the remaining events after the preselection, are given in Table 1.

Table 1: Number of simulated signal and background events before and after the preselection.

Channel	$\tilde{\chi}^0 c \tilde{\chi}^0 \bar{c}$	$q\bar{q}$	WW	eWν	$t\bar{t}$	ZZ	eeZ
(in 1000)	50	6250	3500	2500	350	300	3000
After presel.	47%	46788	115243	252189	43759	4027	4069

4 Iterative Discriminant Analysis

In order to separate the signal from the background, the following selection variables are defined: visible energy, number of jets, thrust value and direction, number of clusters, transverse and parallel imbalance, acoplanarity and invariant mass of two formed jets.

Figure 1 shows the simulated visible energy and transverse momentum after the preselection. Following a tighter preselection, $E_{\mathrm{vis}}/\sqrt{s} < 0.52$ and $N_{\mathrm{cluster}} < 80$, 278377 background events remain. Half of these events and half of the signal events are used to train the IDA [11]. In a first step, a cut on the IDA output variable is applied, defined by a reduction in the signal of 50%. The IDA output variable and the thrust value for the remaining signal and 7265 background events are shown in Fig. 2. These events are again passed through the IDA. Figure 3 shows the IDA output variable and the resulting number of background events as a function of the signal efficiency. For 12% efficiency, 400 background events are expected.

Figure 1: Visible energy and transverse momentum after the preselection.

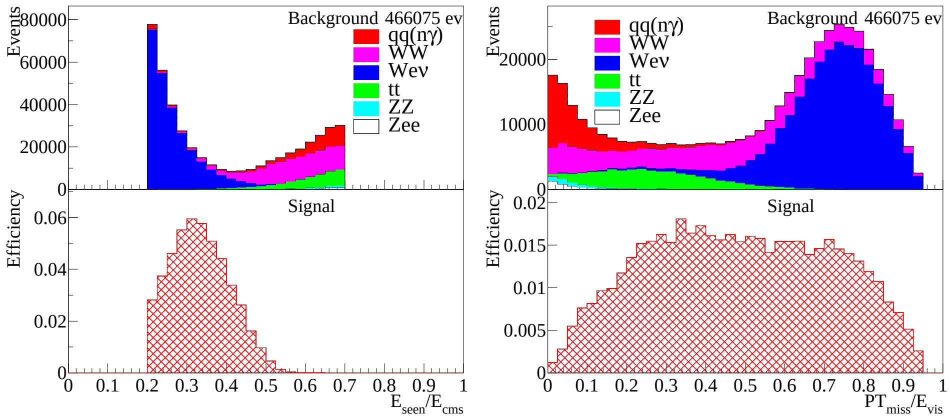


Figure 2: First step IDA output and resulting thrust values.

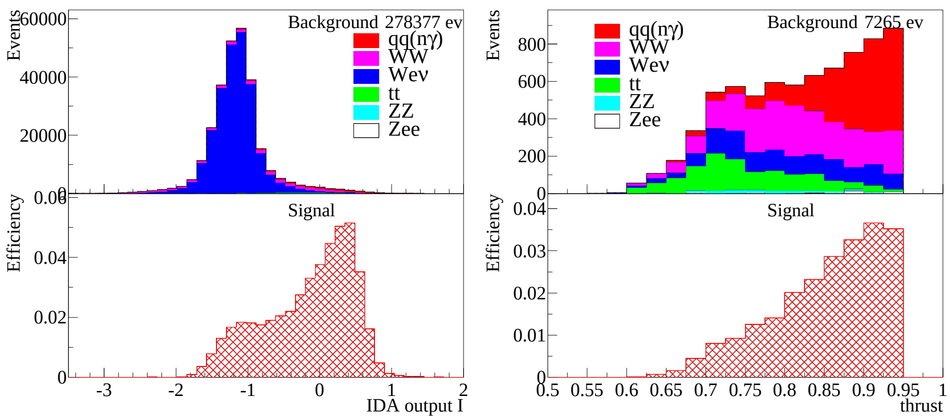
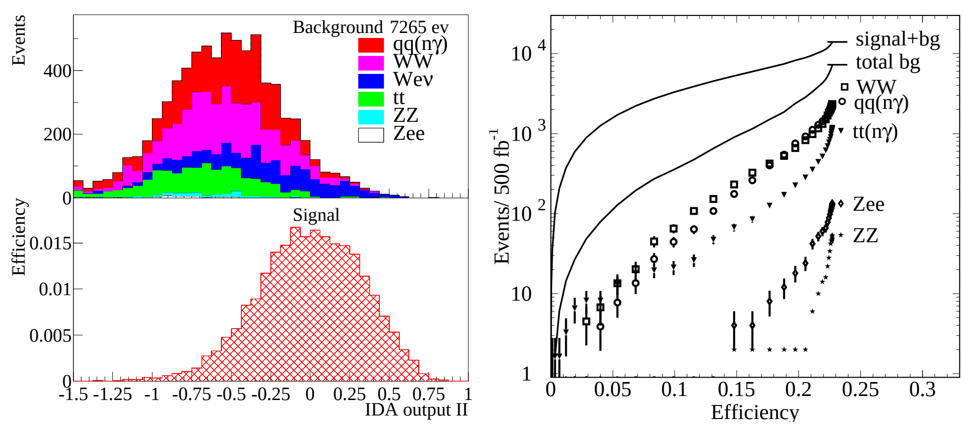


Figure 3: Final IDA output and background vs. signal efficiency for a 180 GeV scalar top and a 100 GeV neutralino.



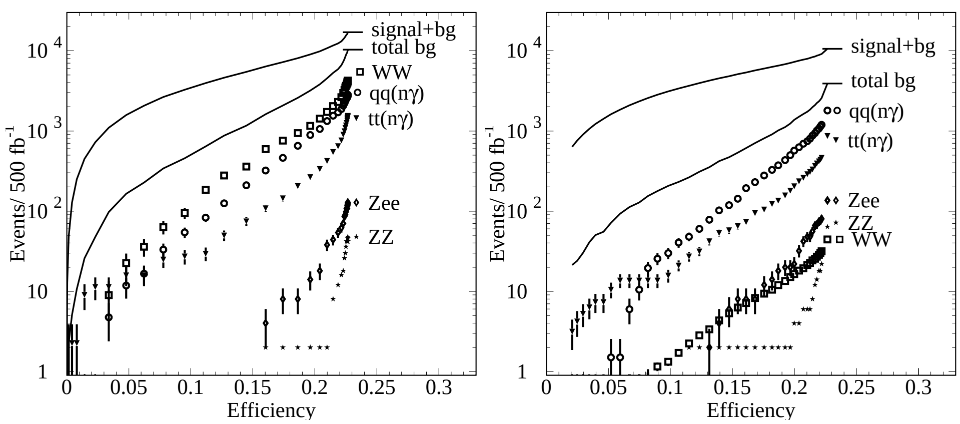
5 Effects of Beam Polarization

The polarization of the e^- beam at a future linear collider offers the opportunity to enhance and suppress the left- and right-handed couplings of the scalar top signal and to determine mass and mixing angle independently. The production cross section of each background process depends differently on the polarization. It is therefore important for a high-statistics analysis to study the expected background channels individually. The expected cross sections are given in Table 2 [12]. The IDA analysis is repeated for -0.9 and 0.9 polarization [b] in order to take into account the different composition of the background and the expected signal cross sections. Figure 4 shows the number of background events as a function of the signal efficiency for left- and right-polarization. For 12% detection efficiency, 650 background events are expected leading to $\sigma_{\text{left}} = 54.5 \pm 1.0$ fb, and 240 background events giving $\sigma_{\text{right}} = 50.9 \pm 1.0$ fb, where $\Delta\sigma/\sigma = \sqrt{N_{\text{signal}} + N_{\text{background}}}/N_{\text{signal}}$.

Table 2: Background cross sections (pb) from different event generators for e^- polarization.

Pol. of e^-	Weν GRACE	WW WOPPER	$q\bar{q}$ HERWIG	$t\bar{t}$ HERWIG	ZZ COMPHEP	Zee PYTHIA
-0.9	6.86	14.9	14.4	0.771	1.17	—
0	5.59	7.86	12.1	0.574	0.864	6.0
0.9	4.61	0.906	9.66	0.376	0.554	—

Figure 4: Background vs. signal efficiency for left- and right-polarization.



6 Results

We have determined the expected background rate for a given signal efficiency and checked that the discovery sensitivity for a 180 GeV scalar top is almost independent of the working point signal efficiency in the range 5% to 20%. The total simulated

[b] For a polarization of -0.9, 95% of the e^- are left-polarized. In the previous analyses [6,7,8] it was assumed that only 90% of the e^- were polarized.

background of about 16 million events is reduced to a few hundred, which allows a precision measurement of the scalar top production cross section with a relative error of better than 2%. Figure 5 shows the corresponding error bands and the error ellipse in the $m_{\tilde{t}_1} - \cos\theta_{\tilde{t}}$ plane. The errors are a factor of 7 better than reported previously [8]. In conclusion, an IDA analysis based on experience at LEP2 was applied and it improved significantly the signal sensitivity. A high-luminosity linear collider with the capability of beam polarization has a great potential for precision measurements in the scalar quark sector predicted by supersymmetric theories.

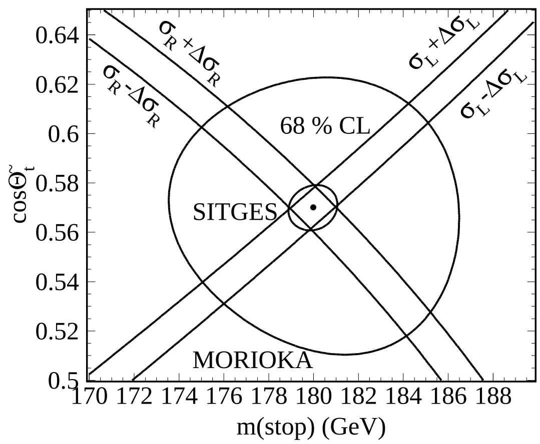


Figure 5: Error bands and the corresponding error ellipse as a function of $m_{\tilde{t}_1}$ and $\cos\theta_{\tilde{t}}$ for $\sqrt{s} = 500$ GeV and $\mathcal{L} = 500$ fb^{-1}. The dot corresponds to $m_{\tilde{t}_1} = 180$ GeV and $\cos\theta_{\tilde{t}} = 0.57$. The errors from the 10 fb^{-1} Morioka study were $\Delta m_{\tilde{t}_1} = 7$ GeV and $\Delta\cos\theta_{\tilde{t}} = 0.06$, while the 500 fb^{-1} Sitges study gives $\Delta m_{\tilde{t}_1} = 1$ GeV and $\Delta\cos\theta_{\tilde{t}} = 0.009$.

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